GREAT LAKES INDIAN FISH AND WILDLIFE COMMISSION

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• MEMBER TRIBES •

MICHIGAN	WISCONSIN		MINNESOTA
Bay Mills Community	Bad River Band	Red Cliff Band	Fond du Lac Band
Keweenaw Bay Community	Lac Courte Oreilles Band	St. Croix Chippewa	Mille Lacs Band
Lac Vieux Desert Band	Lac du Flambeau Band	Sokaogon Chippewa	

Via Electronic Mail December 14, 2015

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Comments on NorthMet FEIS and Section 404 permitting

Re: Mine site groundwater model formulation and calibration.

Since before 2008, GLIFWC staff have consistently raised concerns about the quality and validity of the groundwater characterization at the mine site. Most recently we raised concerns in a pFEIS comment letter of August 11th, 2015. In an October 12, 2015 memo titled: "NMet_Mine Site MODFLOW Calibration-PMP_Response to GLIFWC_Final"(attached) co-leads discussed the groundwater model formulation and calibration yet did not address the primary concern that the current conditions model and the closure models were formulated with boundary conditions that do not currently exist and will not exist in the future. The FEIS does not address those concerns in any way and those concerns remain. For a discussion of our concerns raised in August refer to our August 11th letter (available at: http://www.lic.wisc.edu/glifwc/PolyMet/pFEIS/GLIFWC_comments/groundwater_flow/). This letter elaborates on those comments related to model configuration and calibration. The mine site MODFLOW model was incorrectly bounded and calibrated and does not provide the hydrologic characterization of the site that is needed in order to perform adequate project impact evaluations.

GLIFWC is acting in coordination with our member tribes, including the Fond du Lac Band, to review and contribute to the PolyMet EIS process. As you may know, GLIFWC is an organization exercising delegated authority from 11 federally recognized Ojibwe (or Chippewa) tribes in Wisconsin, Michigan and Minnesota.[1] Those tribes have reserved hunting, fishing and gathering rights in territories ceded in various treaties with the United States. GLIFWC's mission is to assist its member tribes in the conservation and management of natural resources and to protect habitats and ecosystems that support those resources. The proposed PolyMet mine is located within the territory ceded by the Treaty of 1854.

Mine-site MODFLOW model calibrated to conditions that rarely exist:

The existing Northshore Peter-Mitchell (P-M) taconite mine pits which are less than 1 mile north of the PolyMet project area, play a significant role in the groundwater hydrology of the project site. In the applicant's groundwater modeling of 2015 (and earlier versions), documented in the "Water Modeling Data Package Vol 1-Mine Site v14 Feb.2015" (FEIS reference PolyMet 2015m, available at: http://www.lic.wisc.edu/glifwc/PolyMet/FEIS/reference/), those pits supply approximately 90% of the groundwater baseflow to the upper Partridge River. It is not surprising that those taconite pits play a significant role in the local groundwater hydrology since they are positioned high in the local terrain, at times contain large volumes of water, and sit in relatively high conductivity bedrock (Biwabik Iron Formation or BIF and Virginia Formation). Because they play a dominant role in the local hydrology, it is critical that they be correctly incorporated into the project hydrologic modeling.

Unfortunately, the existing project MODFLOW model for the PolyMet mine site was calibrated using P-M taconite pit water levels that were 13 or more meters too high. The project model incorporates the P-M pits as constant-head-cell boundary conditions (FEIS Figure 5.2.2-2 or attached as Figure 1). The project model sets the P-M pit lakes as constant-head-cells approximately 5 meters above the level of the upper Partridge River, yet pit lakes during the period when flow data was collected (1979-88) were actually well below the elevation of the upper Partridge. Because of this error, the calibration model has the local direction of groundwater flow from the pits 180 degrees reversed from the actual conditions during the calibration period. The model predicts that during the calibration period water was flowing from the hydrologic high at the P-M pits to the hydrologic low at the upper Partridge River, when in fact, because the pits were partly to completely empty, water would have been flowing from the upper Partridge River to the P-M pits.

Attached is a figure that shows the predicted water tables and groundwater flow between the upper Partridge and the P-M pits when the P-M pits are set at different levels (attached as Figure 2). In red are the project model results used in recent and past project reports. In those models the P-M pits are assumed to be at their 1996 elevation of 493 meters (1616 feet). The 483 meter model (in purple) is the same as the project model except that the water levels in the P-M pits, that are adjacent to the upper Partridge, are set to 483 meters. An average pit water elevation of less than 480 meters appears to be the correct elevation for the calibration period of 1979-1988 (attached as Table 1). Calibration and use of the MODFLOW model with the P-M pits erroneously set to the unusually high conditions in 1996 (493 meters) is a problem for the following reasons:

- The baseflow used in formulating (calibrating) the PolyMet project MODFLOW mine site model was calculated from flow conditions in the 10 years of 1979 through early 1988. During

1 GLIFWC member tribes are: in Wisconsin -- the Bad River Band of the Lake Superior Tribe of Chippewa Indians, Lac du Flambeau Band of Lake Superior Chippewa Indians, Lac Courte Oreilles Band of Lake Superior Chippewa Indians, St. Croix Chippewa Indians of Wisconsin, Sokaogon Chippewa Community of the Mole Lake Band, and Red Cliff Band of Lake Superior Chippewa Indians; in Minnesota -- Fond du Lac Chippewa Tribe, and Mille Lacs Band of Chippewa Indians; and in Michigan -- Bay Mills Indian Community, Keweenaw Bay Indian Community, and Lac Vieux Desert Band of Lake Superior Chippewa Indians.

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calibration, the MODFLOW model's formation conductivities were adjusted until the baseflow it predicted matched the 0.51 cfs baseflow target at station SW003, where the Dunka Road crosses the Partridge River.

- The average water level in the P-M pits, when the baseflow at SW003 was estimated to be 0.51 cfs (i.e. in the 10 years of 1979 to early 1988), was actually more than 13 meters lower than the 1996 levels, at less than 480 meters.

As the diagram shows, with the pit water levels that occurred in November of 1986 (i.e. ~483 meters), the upper Partridge would have been losing water to the pits and would have had no baseflow. The water table would have sloped down northward from the Partridge River toward the P-M taconite pits. This is because the riverbed of the upper Partridge River is at 486-489 meters elevation, whereas the water levels in the adjacent P-M pits were at approximately 483 meters elevation in 1986. Average water levels in the P-M pits during the 10 years for which baseflow was calculated (1979-1988) were *even lower* than the 483 meter elevation found in 1986.

Water levels in the Peter-Mitchel Area003-east pit:

Water levels in the P-M Area003-East pit (Table 1 and Figure 5) increased from an elevation of less than 478 meters in 1979 to 488 meters in the fall of 1987. During most of that period the Area003-East pit was empty, i.e. less than 478 meters elevation. In contrast, the 1996 water level used for the Area003-East pit during Barr Engineering's model runs was 492.6 meters (1616 feet) elevation.The 1996 water level used for the P-M pits as a boundary condition in the modeling was abnormally high. Such high levels did not occur in the 1980s, do not occur now and will not occur at closure.

The significance of this is that using the high 1996 Peter-Mitchel pit water levels during calibration is likely to have resulted in restrictive (i.e. low) formation conductivities and recharge in order to force the model to match calibration targets. In order to conservatively estimate maximum PolyMet project pit inflows, the models should have been calibrated with realistic P-M water levels and only during pit inflow predictive runs should the P-M pit water levels been raised to their likely maximum level such as that found in 1996. Such procedures for worst-case scenario analysis (Anderson et al. 2015, Section 10.4.1 Scenario Modeling) is basic to hydrologic modeling.

Lack of model sensitivity analysis for major internal fixed boundary conditions:

Contrary to Barr's statements in the Model Technical Review Checklist (MTRC) section (PolyMet 2015m.pdf document page 2971), the MODFLOW model was not evaluated to sensitivity of some of the most significant boundary conditions, the constant-head boundary conditions representing the P-M taconite pits. That quality control document has errors and misstatements, raising questions about adequate quality control. For example the local scale models were 8 layers, not the 7 stated in the MTRC, and the software used for the base case was outdated MODFLOW96 not the current industry standard MODFLOW-NWT. These errors cast doubt on the adequacy of the review to which the groundwater models were subjected.

If, as claimed in the MTRC, a sensitivity to the model boundary conditions had been done, it would have been obvious that the models are very sensitive to the levels specified at the nearby taconite pits. GLIFWC's water budget analysis of the PolyMet MODFLOW models suggest that approximately 90% of upper Partridge River baseflow comes from the P-M pits when the P-M are at their 1996 level and the shape of the watertable and bedrock potentiometric surface is highly dependent on the P-M pits boundary condition in the model.

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Sensitivity analysis as a substitute for correct model bounding and calibration:

The co-lead memo of October 12th proposes that sensitivity analysis on one parameter, baseflow (Barr 2015d, Appendix K), can substitute for understanding site hydrology. While sensitivity analysis on a properly bounded and calibrated model provides insights on the range of possible predictions, sensitivity analysis conducted on a mis-configured model cannot be depended upon.

Incorrectly bounded closure model:

The closure period model, on which the sensitivity analysis was conducted, was configured with boundary condition in the form of P-M pit water levels at their 1996 levels, over 300 feet higher than the water levels actually expected at closure. Those P-M pits are close to the center of the model used for sensitivity analysis and, therefore, erroneous boundary conditions of this magnitude invalidate the results of the sensitivity analysis. Not only was the calibration model incorrectly bounded but the closure predictive runs use the same abnormally high P-M pit water levels. In particular the predictive runs for long-term closure (MODFLOW run "SS_west_fill_Sept2014_1585ec1595" resulting in Large Figures 29 and 30 of PolyMet 2015m) use the 1996 taconite pit water levels that are over 300 feet higher than the expected closure water levels.

Widespread role of MODFLOW in PolyMet's analyses and the FEIS:

The essential role of groundwater system characterization, characterization that integrates information from the available sources into a coherent model, is demonstrated by the myriad of uses to which the project groundwater model (MODFLOW) has been put by the applicant during impact evaluation. We have compiled, from the text in PolyMet 2015m and the FEIS, references to the use of the groundwater modeling to predict impacts from the proposed project. Those uses range from contaminant flow direction and gradients, to delineation of the Area of Potential Effect for cultural impacts (FEIS page 4-313 and Figure 4.2.9-5). Project documents include very clear statements about the importance of MODFLOW in formulating impacts, for example PolyMet 2015m Section 5.1.2.6 states:

> "Groundwater contours for the unconsolidated deposits and bedrock are the primary source of information used to delineate the flow path areas. The groundwater contours are from the Mine Site MODFLOW model"

The GoldSim contaminant transport modeling in particular uses many outputs from the MODFLOW groundwater modeling (attached as Tables 2 and 3). These extend far beyond the stated purpose of the groundwater model; which in one of several statements was to "estimate the amount of pit inflow and evaluate groundwater flow conditions following pit closure (SDEIS reference Polymet 2013i; available at: http://www.lic.wisc.edu/glifwc/polymet/sdeis/references/), thus making it very clear that a valid model that characterizes site groundwater hydrology is foundational for impact prediction.

The project MODFLOW model was used to characterize post closure contaminant flow paths (Large Figures 28 & 29 of PolyMet 2015m , attached as Figures 3 & 4, and FEIS Figure 5.2.2-7) and the general nature of the groundwater system such as mine site groundwater levels at closure (e.g. Large Figure 30 of Attachment B of PolyMet 2015m, attached as Figure 6). In addition, the MODFLOW model was used to supply the numeric input parameters to the GoldSim model that is used for prediction of contaminant flow and contaminant concentrations (PolyMet 2015m , Table 1-1). That table, attached as Table 3, identifies critical GoldSim input parameters that are outputs from the mine site MODFLOW groundwater model. Those parameters include contaminant flowpath conductivity (K_flowpath), flowpath gradients (I_ops), bedrock porosity (Bedrock_Porosity), recharge (Recharge_min and Recharge_max) and flowpath gradients at closure (I_close). While some of these parameters, such as flowpath conductivity, are secondarily derived from MODFLOW outputs, MODFLOW is an input to

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calculation of the GoldSim parameters, as documented in PolyMet 2015m Section 5.2.3.3.

Despite the widespread use of MODFLOW outputs in the evaluation of the project site and developing the basis for the FEIS, there have been repeated attempts by PolyMet and the co-leads to claim that the MODFLOW model was intended only to look at pit inflow. That is simply not true.

In a 2012 technical memo of the Water Modeling Data package of the SDEIS (SDEIS reference PolyMet 2013i), Barr Engineering stated:

> "The primary objectives of the models were to:
> - Estimate the amount of groundwater inflow that can be expected to flow into the mine pits during operations and pit filling, and
> - Evaluate groundwater flow conditions following pit closure."

In Attachment B of the FEIS reference PolyMet 2015m, Barr stated that:

> "The primary objective of this study was to estimate the amount of groundwater expected to flow into the mine pits during operations and pit flooding, and to evaluate the groundwater flow conditions following pit closure."
>
> and presented model results on mine pit outflow:
>
> "Simulated groundwater flow rates for the long-term closure simulations are shown in Table 4-4." and "Table 4-4 Estimated Groundwater Inflow and Outflow Rates – Long-term Closure Conditions"

In their October 12 memo (attached) the co-leads make yet another characterization of modeling purpose:

> "The stated purpose of the MODFLOW model is to predict pit inflows and characterize hydrogeologic conditions between the NorthMet mine pits and the Partridge River."

While we don't disagree that these as some of the purposes to which MODFLOW was put, we believe that the many written statements by PolyMet and the co-leads and the many uses that the MODFLOW results were put to in writing the FEIS (documented in the previous paragraphs) most completely illustrate the true uses of the MODFLOW modeling in this project.

It is clear that without the conceptual (flow directions etc.) and numeric (gradient, conductivity etc.) outputs from the MODFLOW model, the GoldSim model could not be run. Because of the dependence of the GoldSim modeling of contaminant transport on MODFLOW model outputs, it is essential that the MODFLOW outputs be valid. Because the MODFLOW closure models were incorrectly bounded with taconite pit water levels that were 300 feet in vertical error and the base models calibrated to atypically high taconite pit water levels, it is very unlikely that the MODFLOW model outputs are correct.

In summary:

- The boundary conditions in the MODFLOW current conditions model and in the predictive closure model were far from correct. In particular, the predictive closure models, which were used to identify flow direction and quantity from the PolyMet pits, used boundary conditions that were over 300 feet in error. Sensitivity analysis of both the current conditions calibration model and the predictive closure model to taconite mine pit water levels should have been conducted.

- Results from MODFLOW modeling were used throughout development of the FEIS. They were used to characterize groundwater flow patterns prior to mining, during mining, and after closure of the PolyMet project. Outputs from MODFLOW were used for everything from identifying waters that may be impacted, to identifying the Area of Potential Effect for cultural resources, to calculating groundwater inflow and outflow from pits, to identifying contaminant flowpaths and water quality compliance evaluation points.

- The project mine site groundwater flow model (MODFLOW) was calibrated with multiple conditions that did not exist simultaneously, i.e. boundary conditions in the form of taconite pit water levels from 1996 and river baseflows from 1979-88. This means that the mine site model is not correctly configured and, therefore, unlikely to generate accurate predictions.

-There is no consistent conceptual model of site hydrology. The conceptual model used for the basis of many of the conclusions in project reports and in the FEIS text is that the nearby taconite pits have little influence on the surrounding aquifer, regardless of whether they are full of water or pumped dry. This is a notion that was proposed early in the project and drove many of the data collection and EIS decisions. On the other hand, the mine site MODFLOW model, which incorporates historical and site-specific conductivity data on the bedrock formations and is used by the applicant to predict closure conditions, indicates that the nearby taconite pits have a profound impact on the surrounding aquifer.

- The project MODFLOW model was configured and used by the applicant as a basis for contaminant transport predictions at closure. Given that it is mis-configured with grossly incorrect closure pit water levels, it cannot give reliable predictions of contaminant flow direction or quantity.

The mine site groundwater models need to be reconfigured to contain realistic water levels in the P-M taconite pits, both for a "current conditions" model and a "closure conditions" model, not the 1996 water levels that were unusually high. The predictive MODFLOW modeling for the closure period must use the correct closure water elevations for the P-M pits which are 300 feet lower than the unusually high 1996 levels that are used for FEIS predictions. Sensitivity analysis and adaptive management cannot be substitutes for consistent and rational characterization of site hydrology.

Sincerely,

John Coleman

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Table 1. Peter-Mitchel pit water levels.

The pit number correspond to the pits in the attached map.

	<-west			pit				east->
	8	7	6*Area3-West	5*Area3-East	4 Area2	3	2	1
year		SD011-12	SD008-10	SD006-7	SD005	SD004		SD002
1978/09		empty	~empty	**empty**	empty	empty	empty	
1979/09		empty	empty	**empty**	empty	empty	empty	
1980/10		empty	empty	**~empty**	empty	empty	empty	
1985/10		~empty	~empty	**<477.9**	~empty	~empty	~empty	~empty
1986/11				**483.4**				
1987/09				**487.7**				
1988/04				488.3				
1989/10				492.6	492.6			
1991/09		499.0	494.0	494.4	492.6			
2011/05	498.74	499.50	494.4	477.6	460.0	425.1	452.3	432.7
Barr MODFLOW runs (1996)	488.3	500.1	492.6	492.6	missing	475.5	475.5	
Partridge @ SW001			489.7					
confluence of Yelp and Partridge			487.0					
Partridge & RR grade (SW002)			486.8					

*headwaters of Partridge River/Yelp Cr.

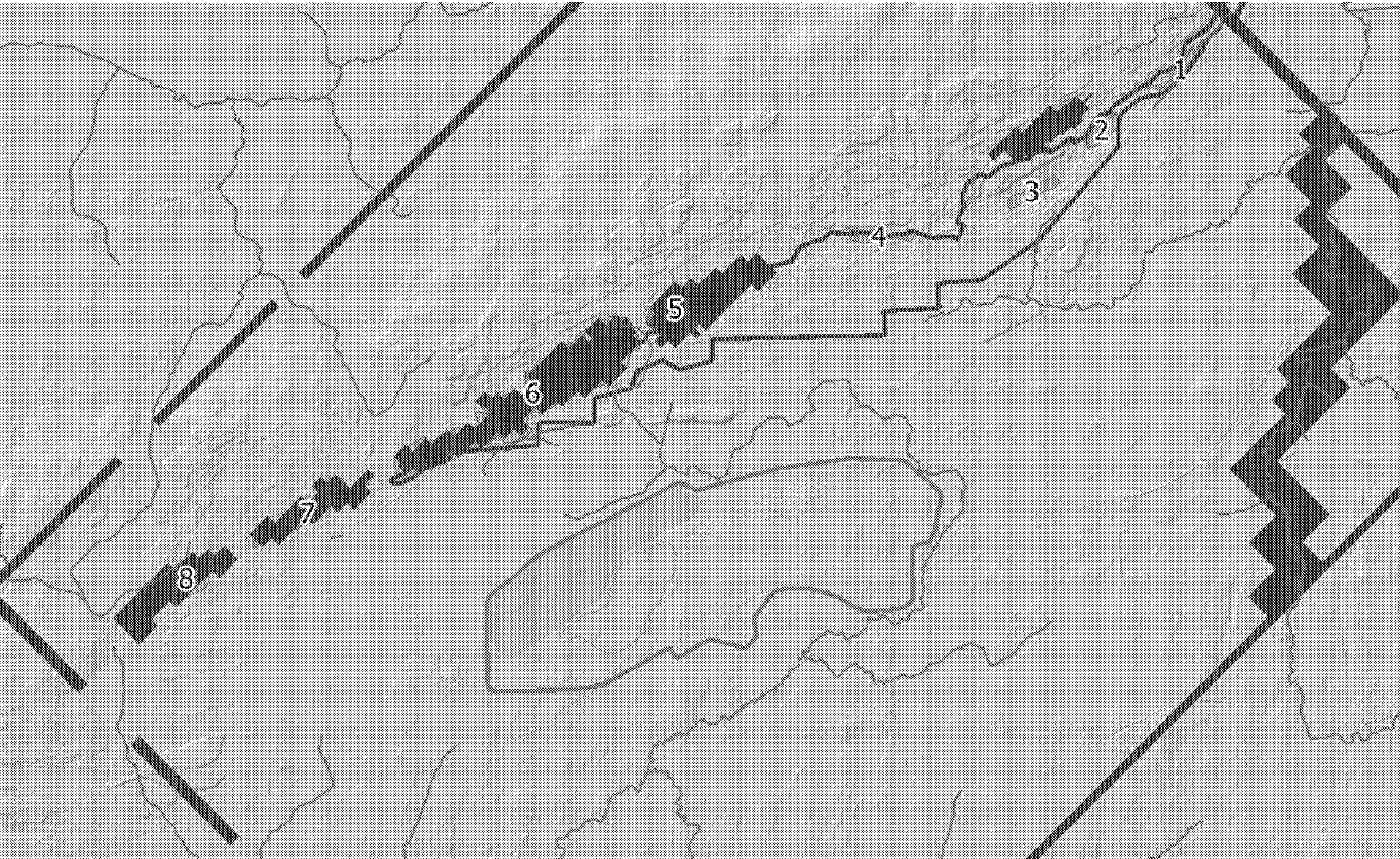
1
2
3
4
5
6
7
8

Table 2. MODFLOW modeling results used for Goldsim modeling of contaminant transport as reported in the water modeling report "Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf".

Establish general groundwater head distribution (e.g. watertable):	Section 5.2.3.7 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 124 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf and Large Figs. 14 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 492 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)
Establishing contaminant flow paths:	Section 5.2.3 and Large Figs. 28-29 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 114 and 511 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf) and Section 5.2.3.7 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 124 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)
Establishing gradients along contaminant flow paths:	Section 5.2.3.1 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 118 Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)
Establishing hydraulic conductivity along contaminant flow paths:	Section 5.2.3.7 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 125 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf) and Section 3.2.5.5 and Large Fig. 18 of Attachment B Groundwater Modeling of the NorthMet Mine Site (.pdf page 662 and 702 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)
"Infiltration" along contaminant flowpaths for calculation of baseflow:	Section 5.2.4.3.5 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 141 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)

Pit inflows used for "overall water balance in the probabilistic model" (contaminant transport model):	Section 5.2.3.7 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 125 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf) and Section 6.1.2.3.2 of Water Modeling Data Package Volume 1 - Mine Site (.pdf page 177 of Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf)
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Table 3. Parameters used in GoldSim modeling. from the Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf

Table 1-1 Input Variables for the Mine Site Model

Variable Name	*Units*	*Deterministic/ Uncertain*	*Sampling/ Calculation Frequency*	*Distribution*	*Mean or Mode*	*Standard Deviation*	*Minimum*	*Maximum*	*Description*	*Source of Input Data*	*Modeling Package Section*
Grey cells indicate changes from the previously published version											
Climatic Variables											
Annual_Precip_Cuberoot	[$in^{1/3}$]	Uncertain	Annual	Trunc. Normal	3.05	0.16	0	N/A	Cube root of the annual precipitation	HiDen Climate network for Mine Site (1980-2010 climate normal)	Water Section 5.2.1 *Climate Inputs*
Monthly_Precip_Factors	[%]	Deterministic	N/A	Constant	Vector by month. Reference Table 1-11				Factors for partitioning annual precipitation to monthly	HiDen Climate network for Mine Site (1980-2010 climate normal)	Water Section 5.2.1 *Climate Inputs*
Annual_Evap	[in/yr]	Uncertain	Annual	Normal	20.8	1.33	N/A	N/A	Annual evaporation from open water	HiDen Climate network for Mine Site (1980-2010 climate normal); Baker (1979)	Water Section 5.2.1 *Climate Inputs*
Monthly_Evap_Factors	[%]	Deterministic	N/A	Constant	Vector by month. Reference Table 1-11				Factors for partitioning annual open water evaporation to monthly	Baker (1979) for partitioning ratios	Water Section 5.2.1 *Climate Inputs*
Snowmelt	[--]	Deterministic	N/A	Constant	4	N/A	N/A	N/A	Month when snowmelt occurs	USGS Gage Data	Water Section 6.1.3.3 *Water Balance, Mine Pits*
Freezeup	[--]	Deterministic	N/A	Constant	11	N/A	N/A	N/A	Month when freezeup occurs, consistent with WWTF design team definition	USGS Gage Data	Water Section 6.1.3.3 *Water Balance, Mine Pits*
Background Chemistry											
GW_Conc_Surf	[mg/L]	Uncertain	Realization	Transformed Normal	Vector by Constituent. Reference Table 1-12				Surficial groundwater concentrations in the Partridge River watershed	Analysis of PolyMet background water quality data	Water Section 5.3.1 *Background Groundwater*
GW_Conc_Bed	[mg/L]	Uncertain	Realization	Transformed Normal	Vector by Constituent. Reference Table 1-12				Bedrock groundwater concentrations in the Partridge River watershed	Analysis of PolyMet background water quality data	Water Section 5.3.1 *Background Groundwater*
SW_Conc_RO	[mg/L]	Uncertain	Month	Lognormal	Vector by Constituent. Reference Table 1-13				Calibrated surface runoff concentrations in the Partridge River watershed	Calibration of model to baseline conditions	Water Section 5.3.1 *Background Surface Runoff*
SW_Conc_PMP	[mg/L]	Deterministic	N/A	Constant	Vector by Constituent. Reference Table 1-13				Concentration leaving the Peter Mitchell Pits	2004-2007 WQ modeling at SW-001	Water Section 5.5.3.1 *Other (Non-Project) Loads*
Flow_PMP	[cfs]	Deterministic	N/A	Constant	2.6	N/A	N/A	N/A	Flow from Peter Mitchell Pit dewatering to SW-001	Calibration of model to baseline conditions	Water Section 5.5.3.1 *Other (Non-Project) Loads*
Flow_PMP_end	[yr]	Deterministic	N/A	Constant	55	N/A	N/A	N/A	Mine Year when flow from Peter Mitchell Pit ends, equivalent to year 2070	Northshore Mine Plan	Water Section 5.5.3.1 *Other (Non-Project) Loads*
SW_Conc_Partridge	[mg/L]	Deterministic	N/A	Constant	Matrix by Constituent and location. Reference Table 1-14				Baseline existing chemistry in Partridge River used to evaluate model	2004-2010 Monitoring Data of Partridge River	Water Section 4.4.4.1 *Water Quality ,Partridge River*
Load_Colby	[kg/yr]	Deterministic	N/A	Constant	Vector by Constituent. Reference Table 1-13				Calibrated additional loading to Colby Lake	Calibration of model to baseline conditions	Water Section 5.5.3.1 *Other (Non-Project) Loads*
Groundwater Flowpath Characteristics											
I_ops	[--]	Uncertain	Realization	Uniform	Vector by flowpath. Reference Table 1-15				Average hydraulic gradient along aquifer	Mine Site MODFLOW model	Water Section 5.4.1 *Groundwater Flowpath Modeling*
I_close	[--]	Uncertain	Realization	Uniform	Vector by flowpath. Reference Table 1-15				Average hydraulic gradient along aquifer in closure	Mine Site MODFLOW model	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Thick	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Aquifer thickness	Assumed value	Water Section 5.4.1 *Groundwater Flowpath Modeling*
EL_Pit	[ft]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Pit surficial outflow elevation	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Width	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Flowpath width	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Upstream	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Length upstream of stockpile	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Stock	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Source (stockpile) length	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Eval_1	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Length to Evaluation Point #1	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Eval_2	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Length to Evaluation Point #2	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Eval_3	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Length to Evaluation Point #3	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*
L_Total	[m]	Deterministic	N/A	Constant	Vector by flowpath. Reference Table 1-15				Total flowpath length	GIS data/calculations	Water Section 5.4.1 *Groundwater Flowpath Modeling*

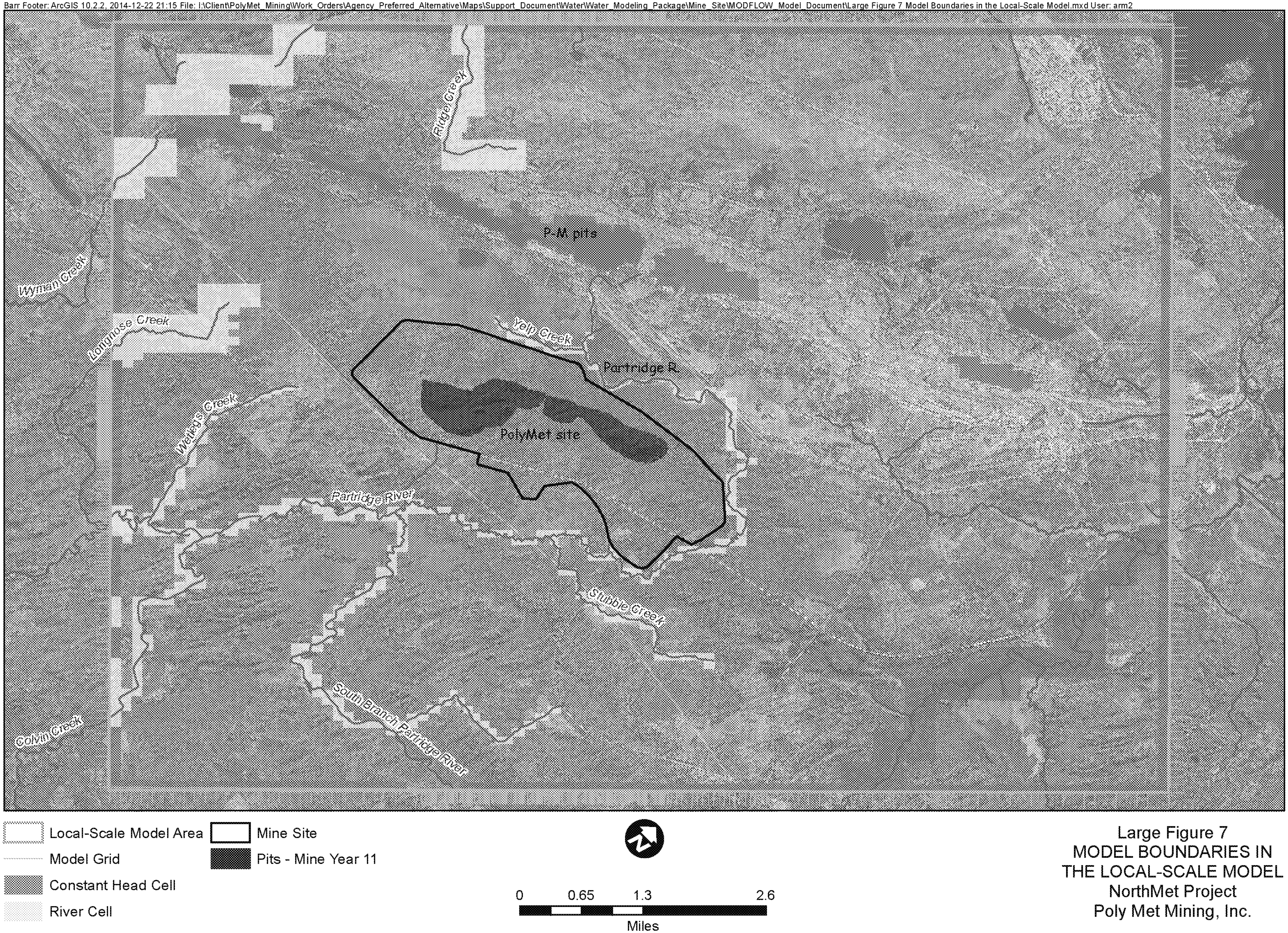
Table 3, continued.

Table 1-1 **Input Variables for the Mine Site Model**

Variable Name	*Units*	*Deterministic/ Uncertain*	*Sampling/ Calculation Frequency*	*Distribution*	*Mean or Mode*	*Standard Deviation*	*Minimum*	*Maximum*	*Description*	*Source of Input Data*	*Modeling Package Section*
Grey cells indicate changes from the previously published version											
Groundwater Flow Variables											
Bedrock_Porosity	[--]	Deterministic	N/A	Constant	0.05	N/A	N/A	N/A	Porosity of the bedrock flowpaths	Mine Site MODFLOW model (Bedrock units)	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Surficial_Porosity	[--]	Deterministic	N/A	Constant	0.3	N/A	N/A	N/A	Porosity of the surficial flowpaths	Assumed value, e.g. Fetter, 2001	Water Section 5.4.1 *Groundwater Flowpath Modeling*
K_Flowpath	[m/d]	Uncertain	Realization	Triangular	Vector by flowpath. Reference Table 1-15				Hydraulic conductivity of the surficial and bedrock material	Mine Site MODFLOW model (Duluth Complex), constraints discussed in Water Section 5.4.1	Water Section 5.4.4 *Groundwater Transport in GoldSim*
Recharge_min	[in/yr]	Deterministic	N/A	Constant	0.36	N/A	N/A	N/A	Minimum allowed recharge in surficial aquifer (for checking calculated value)	Mine Site MODFLOW model	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Recharge_max	[in/yr]	Deterministic	N/A	Constant	1.8	N/A	N/A	N/A	Maximum allowed recharge in surficial aquifer (for checking calculated value)	Mine Site MODFLOW model	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Surficial_Density	[kg/m3]	Deterministic	N/A	Constant	1,500	N/A	N/A	N/A	Dry (bulk) Density of the surficial deposits	USDA St. Louis County Soil Survey Database	Water Section 5.4.1 *Groundwater Flowpath Modeling*
Kd_Surficial	[L/kg]	Deterministic	N/A	Constant	Vector by Constituent. Reference Table 1-16				Sorption coefficients for the surficial aquifer (As, Sb, Cu, Ni)	EPA screening-level values	Water Section 5.4.3 *Sorption*
Stream Reach Characteristics											
Segment_Area	[m^2]	Deterministic	N/A	Constant	Vector by location. Reference Table 1-17				Cross sectional area of each segment upstream of each node	RS26 geomorphic surveys	Water Section 5.5 *Surface Water Modeling*
Segment_Length	[m]	Deterministic	N/A	Constant	Vector by location. Reference Table 1-17				Length of river upstream of each node	GIS data	Water Section 5.5 *Surface Water Modeling*
Colby_Volume	[acre-ft]	Deterministic	N/A	Constant	5,300	N/A	N/A	N/A	Colby Lake storage volume from RS73B	DNR bathymetric maps (summarized in RS73B)	Water Section 6.1.5 *Water Balance, Colby Lake*
Contributing_Area	[acre]	Deterministic	N/A	Time Series	Matrix by location and year. Reference Table 1-18				Contributing watershed area to each river node (incremental), used to calculate recharge	XPSWMM Model GIS analysis	Water Section 5.6.4 *Modeling Future Conditions*
Stream Flow Variables											
Streamflow_SW006_(Month)	[cfs]	Uncertain	Timestep	User-defined	Imported from worksheet. Reference Table 1-19				Randomly sampled daily streamflow at SW-006 for each month	USGS gage data (corrected for PMP dewatering)	Water Section 5.6.5 *Developing Probabilistic Model Inputs*
Inc_Flow_Factor_(Month)	[--]	Deterministic	N/A	Time Series	Imported from worksheet. Reference Table 1-20a through 1-20l				Factor to multiply Q at SW006 to get the incremental inflow between nodes for each month	XP-SWMM model results (relative differences)	Water Section 5.6.5 *Developing Probabilistic Model Inputs*
GW_Inc_Baseflow	[cfs]	Deterministic	N/A	Time Series	Imported from worksheet. Reference Table 1-21				Baseflow adding to evaluation points via natural groundwater	XP-SWMM model results scaled to observed baseflow at SW-006	Water Section 5.6.5 *Developing Probabilistic Model Inputs*

Figure 1

Barr Footer: ArcGIS 10.2.2, 2014-12-22 21:15 File: I:\Client\PolyMet_Mining\Work_Orders\Agency_Preferred_Alternative\Maps\Support_Document\Water\Water_Modeling_Package\Mine_Site\MODFLOW_Model_Document\Large Figure 7 Model Boundaries in the Local-Scale Model.mxd User: arm2



Large Figure 7
MODEL BOUNDARIES IN
THE LOCAL-SCALE MODEL
NorthMet Project
Poly Met Mining, Inc.

Figure 2

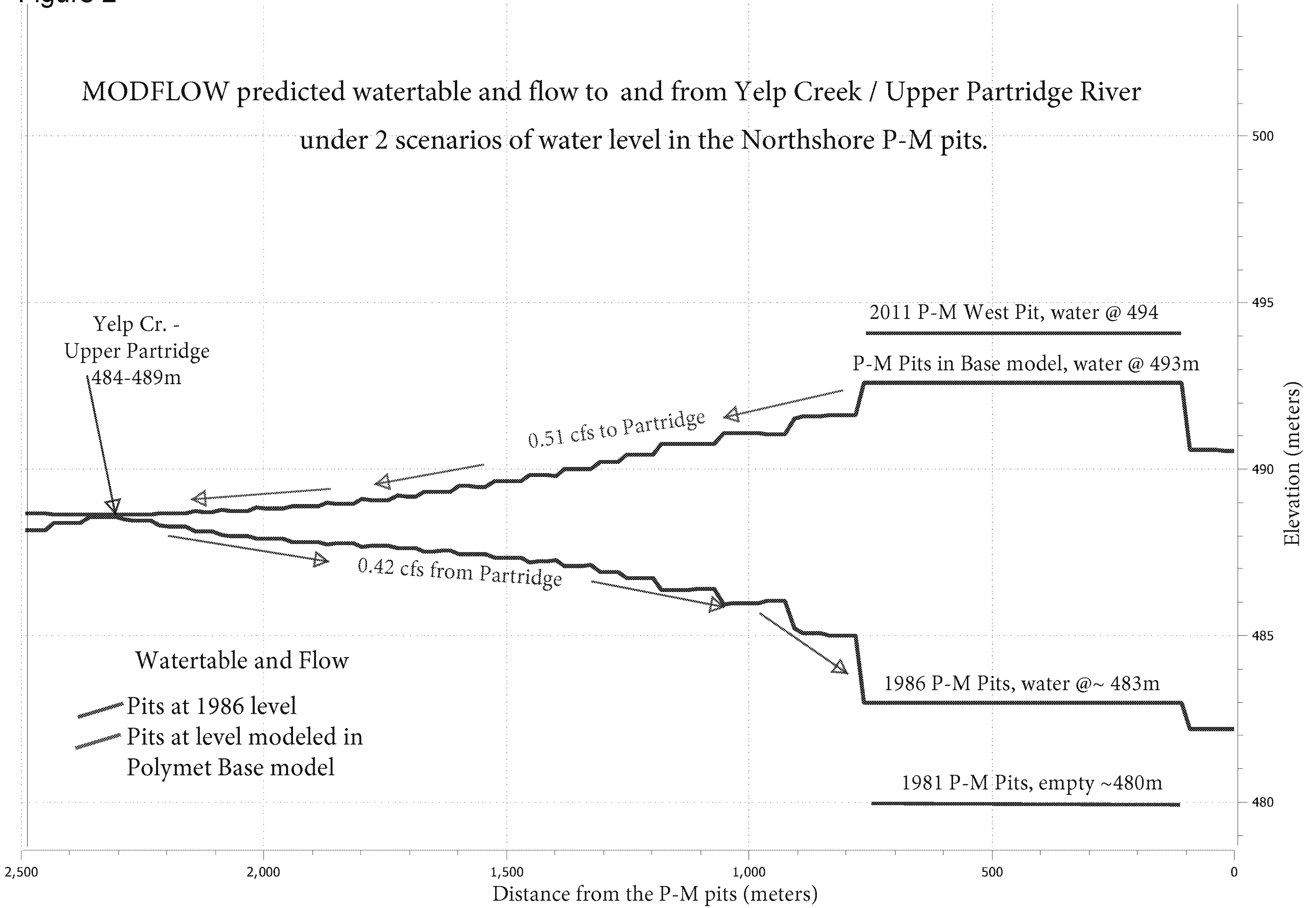
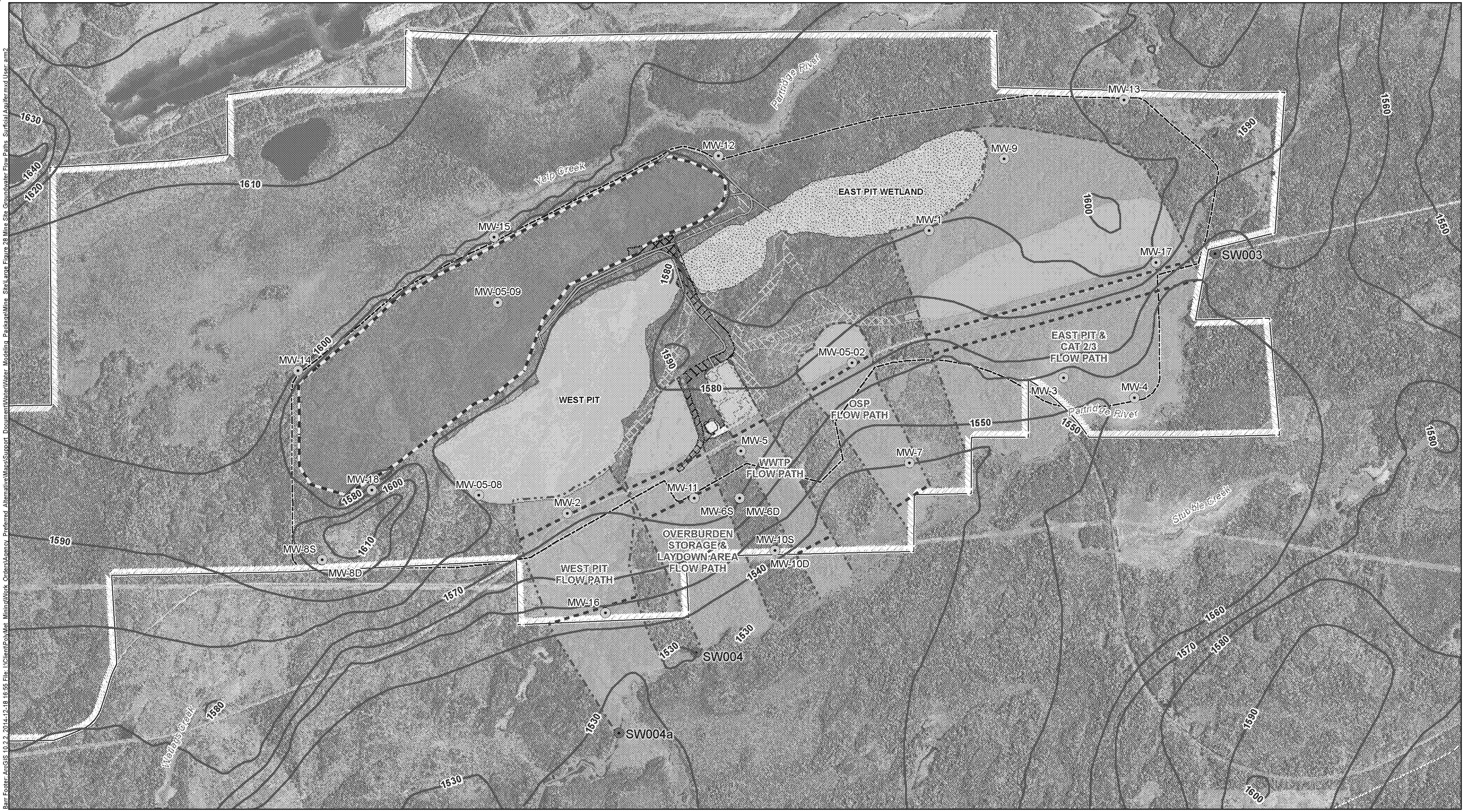

MODFLOW predicted watertable and flow to and from Yelp Creek / Upper Partridge River
under 2 scenarios of water level in the Northshore P-M pits.
Yelp Cr. -
Upper Partridge
484-489m
2011 P-M West Pit, water @ 494
P-M Pits in Base model, water @ 493m
0.51 cfs to Partridge
0.42 cfs from Partridge
1986 P-M Pits, water @~ 483m
1981 P-M Pits, empty ~480m
Watertable and Flow
Pits at 1986 level
Pits at level modeled in
Polymet Base model
500
495
490
485
480
Elevation (meters)
2,500
2,000
1,500
1,000
500
0
Distance from the P-M pits (meters)

Figure 2 - Profile of the water table between the upper Partridge and the P-M pits under 2 scenarios of water level in the pits.

The red stair-step line in the figure is the water table between the upper Partridge R. and the Peter-Mitchel taconite pits when the pits are at 492.6 meters elevation (1616 feet). Water is flowing from the pits to the upper Partridge R.

The purple stair-step line is the water table between the upper Partridge R. and the Peter-Mitchel taconite pits when the pits are at 483.4 meters (1586 feet) elevation (the elevation that they had in 1986). In the 483.4 meter model run, water is flowing from the upper Partridge R., to the P-M pits.

Figure 3



Mine Features

- West Pit
- East Pit Wetland
- Reclaimed Stockpile
- Removed and Reclaimed Stockpile
- Haul Roads
- Reclaimed Haul Roads

- Surface Water Monitoring Location
- Groundwater Monitoring Location
- Groundwater Containment System
- Process Water Pipe
- Groundwater Elevation Contours (Ft) at Closure[1]

[1] Inferred water table contours were developed using contours from the Mine Site MODFLOW model.

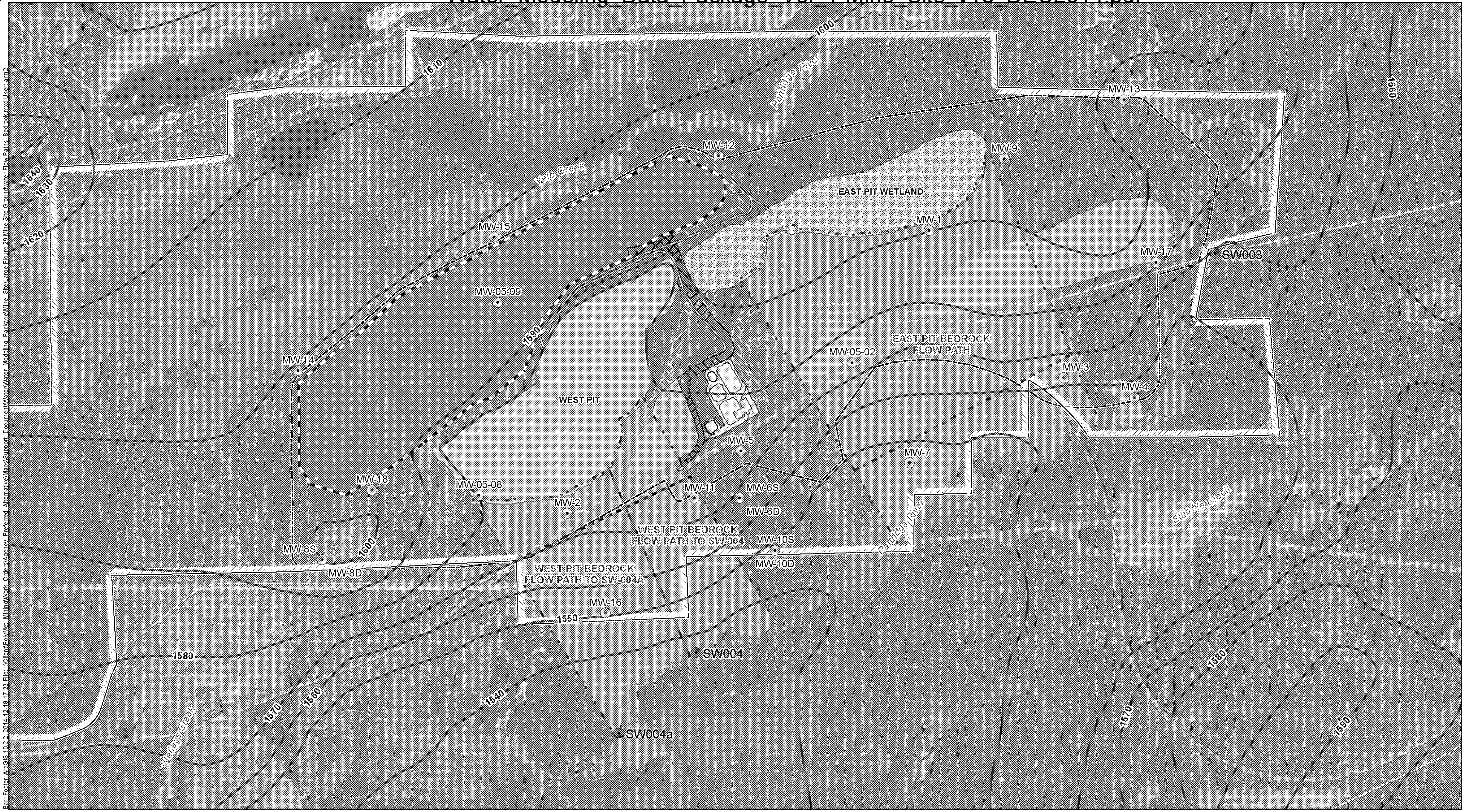
- Groundwater Evaluation Distances
- Groundwater Flow Path
- Mine Site
- Extent of Future PolyMet Lands

0 1,000 2,000 4,000
Feet

Large Figure 28
MINE SITE GROUNDWATER
FLOW PATHS - SURFICIAL AQUIFER
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, MN

Figure 4

Water_Modeling_Data_Package_Vol_1-Mine_Site_v13_DEC2014.pdf



Mine Features
- West Pit
- East Pit Wetland
- Reclaimed Stockpile
- Removed and Reclaimed Stockpile
- Haul Roads
- Reclaimed Haul Roads

- Surface Water Monitoring Location
- Groundwater Monitoring Location
- Groundwater Containment System
- Process Water Pipe
- Groundwater Elevation Contours (Ft) at Closure[1]

[1] Inferred water table contours were developed using contours from the Mine Site MODFLOW model.

- Groundwater Evaluation Distances
- Groundwater Flow Path
- Mine Site
- Extent of Future PolyMet Lands

0 1,000 2,000 4,000

Feet

Large Figure 29
MINE SITE GROUNDWATER FLOW PATHS - BEDROCK
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, MN

Figure 5

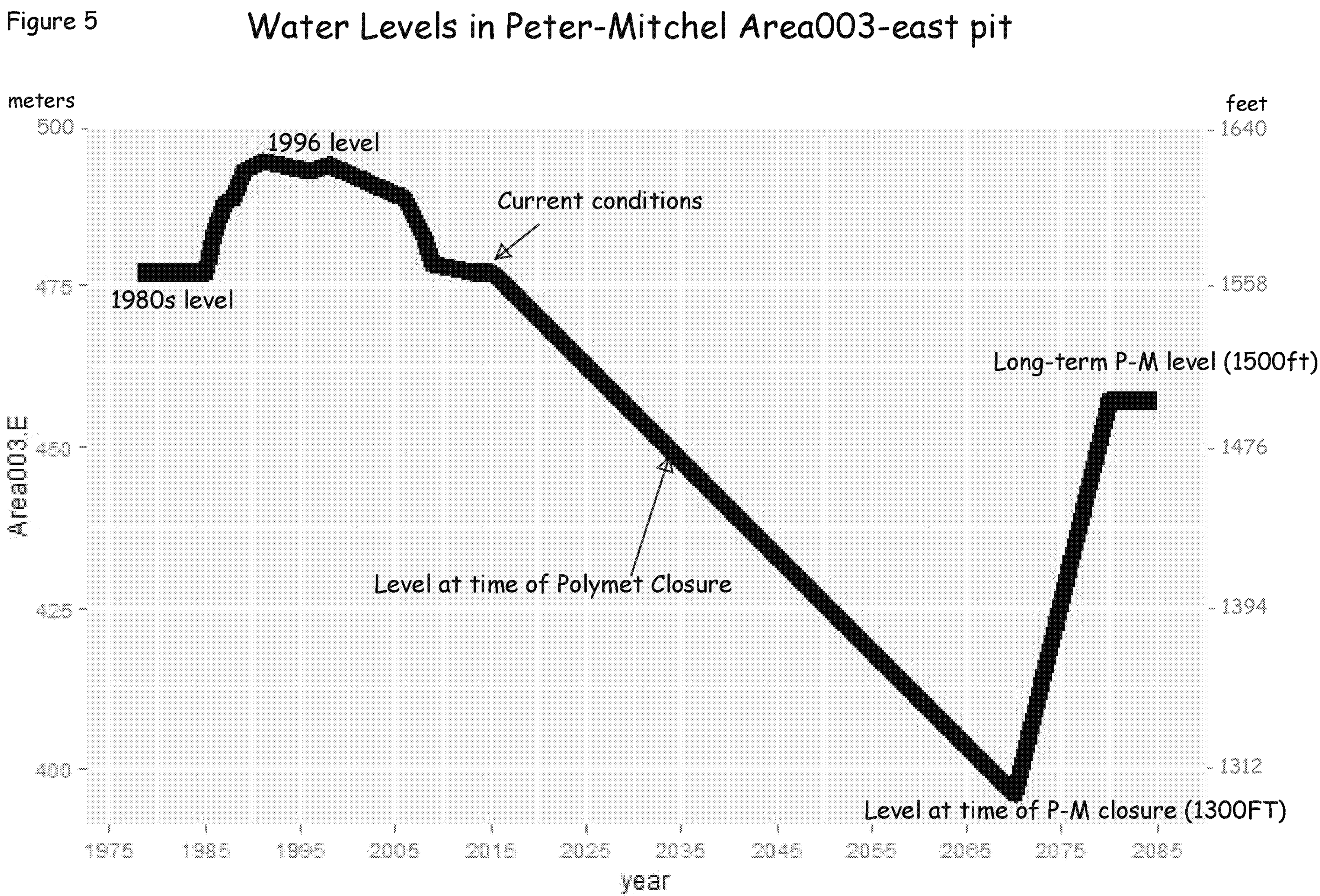
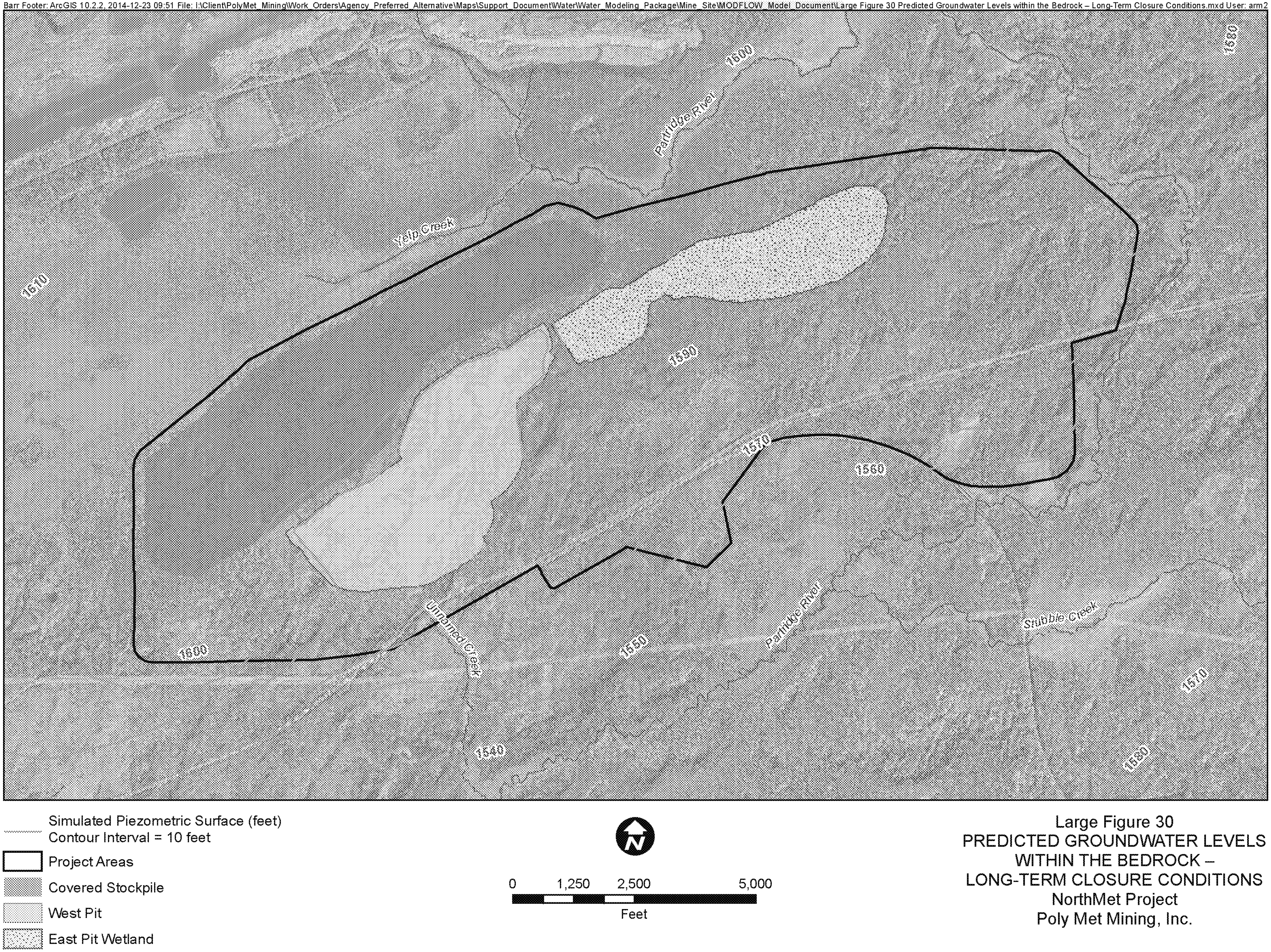

Water Levels in Peter-Mitchel Area003-east pit
meters
feet
500
475
450
425
400
1640
1558
1476
1394
1312
1996 level
Current conditions
1980s level
Long-term P-M level (1500ft)
Level at time of Polymet Closure
Level at time of P-M closure (1300FT)
Area003.E
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
year

Figure 6

Barr Footer: ArcGIS 10.2.2, 2014-12-23 09:51 File: I:\Client\PolyMet_Mining\Work_Orders\Agency_Preferred_Alternative\Maps\Support_Document\Water\Water_Modeling_Package\Mine_Site\MODFLOW_Model_Document\Large Figure 30 Predicted Groundwater Levels within the Bedrock – Long-Term Closure Conditions.mxd User: arm2



Large Figure 30
PREDICTED GROUNDWATER LEVELS WITHIN THE BEDROCK – LONG-TERM CLOSURE CONDITIONS
NorthMet Project
Poly Met Mining, Inc.

INTERAGENCY TECHNICAL MEMORANDUM

To: **Cooperating Agencies in the NorthMet Project EIS**

From: **NorthMet EIS Project Managers**
Michael Jimenez (USFS); Ralph Augustin (USACE); Lisa Fay/Bill Johnson (MDNR)

Re: **NorthMet Environmental Impact Statement**
Co-lead Agencies' Response for GLIFWC Comments on Calibration of the Mine Site MODFLOW Model to Partridge River Groundwater Baseflows

October 12, 2015

The Co-lead Agencies for the NorthMet EIS received comments from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) on the Mine Site groundwater flow model calibration and predictions used for EIS preparation over the period February-April, 2015. GWIFWC's position on this issue was further elaborated in two letters to the Co-lead Agencies, the first on June 18, 2015 with follow-up provided on August 11, 2015. GLIFWC noted that the Mine Site MODFLOW model, which is intended to represent recent conditions, was calibrated using Partridge River groundwater baseflows determined from historic 1980s low flows measured at a downstream gaging station near Colby Lake. GLIFWC further noted that the Northshore pit water level used in the MODFLOW model for calibration (493 m msl) did not conform to the estimated water level (483 m msl) that existed at the time of the stream gaging data used to estimate Partridge River groundwater baseflows.

GLIFWC noted, "The significance of this is that the MODFLOW model was calibrated (adjusted to fit reality) to baseflow in 1986-88, yet the Peter Mitchell pit water levels used as boundary conditions in calibration [493 m msl] were those that occurred in 1996, not those that occurred in 1986-88 [483 m msl]." GLIFWC concludes "this mis-match of boundary conditions and calibration targets is that the model is incorrectly calibrated and cannot be expected to produce accurate predictions."

GLIFWC's interpretation was that the Partridge River groundwater baseflows that occurred during 1980s were lower than recent groundwater baseflows due to the effects of variable water levels in the Northshore pits. GLIFWC asserted that the calibration of the MODFLOW model should use either 1980s Northshore water levels in conjunction with the measured 1980s groundwater baseflows ***or*** recent Northshore pit water levels with estimated recent groundwater baseflows.

Based on the information detailed in the remainder of this Interagency Technical Memorandum, the Co-lead Agencies conclude the groundwater baseflow values used to calibrate the current-conditions Mine Site MODFLOW model, and used as inputs to the GoldSim water quality model, represent reasonable estimates of current hydrologic conditions for the Partridge River at the NorthMet Mine Site.

MNDNR

US Army Corps of Engineers
St. Paul District

The Co-lead Agencies also believe that the separate groundwater baseflow sensitivity analysis adequately addresses GLIFWC's Option #2, (e.g, "recent Northshore pit water levels with estimated recent groundwater baseflows"). The results of the groundwater baseflow sensitivity analysis indicate that estimated constituent concentrations show some sensitivity to the increase in groundwater baseflow values at the respective evaluation locations. Despite this effect, the NorthMet Project Proposed Action does not exceed applicable water quality evaluation criteria. This applies even for the unlikely case of groundwater baseflows being 4 times higher than the values used in the EIS, which is higher than GLIFWC's Option #2. Consequently the Co-lead Agencies conclude that there is no methodology-based justification for changing the groundwater baseflow values used in calibrating the Mine Site MODFLOW and GoldSim models for water resources impact evaluation in the FEIS.

The Co-lead Agencies offer the following response regarding the "groundwater model calibration and predictions" comments as detailed in the June 18, 2015 GLIFWC correspondence. This response is also applicable to comments submitted by GLIFWC on August 11, 2015 regarding a preliminary draft of this same interagency technical memorandum from July 10, 2015. The PolyMet/Barr team supplied information from available data and research to assist the Co-lead Agencies in developing this response.

1.0 Background

As part of the NorthMet EIS water resources impact evaluation, a numerical three-dimensional groundwater flow model was developed by PolyMet for the NorthMet Mine Site and surrounding area. The model was developed using the public domain U.S. Geological Survey (USGS) program MODFLOW NWT in combination with Goundwater Vistas®, a commercially available pre- and post-processor program for MODFLOW. As documented in Mine Site Water Data Package v14 (Barr; February 27, 2015; Attachment B), the base MODFLOW model for the Mine Site effects analysis was a steady-state simulation that was calibrated to:

- recently measured hydraulic heads in surficial deposits (up to 2013);
- measured heads in bedrock (2006 to 2013); and
- groundwater baseflows in the Partridge River using the XP-SWMM surface water model that was calibrated to USGS gage data at SW-006 (Sept 1978 – Nov 1988).

See Table 1 for the Partridge River groundwater baseflow values used in EIS-related modeling.

Table 1 Groundwater Baseflows Used to Calibrate the EIS Mine Site MODFLOW Model

Partridge River Station	Groundwater Baseflow used for FEIS MODFLOW Calibration[a] (cfs)
SW-002	0.41
SW-003	0.51
SW-004	0.92
SW-006 [b]	5.27

[a] Source: Mine Site Water Data Package v14 (Barr; February 27, 2015)
[b] Same as historical USGS gaging station #04015475

For purposes of EIS-related water resources impact assessments the term "groundwater baseflow" is defined as the long-term average discharge to the Partridge River of groundwater from regional surficial deposits and bedrock excluding the Northshore Mine area. It is acknowledged that groundwater baseflow values vary from year to year due to weather variations. Thus, the characterization of groundwater baseflow as a single value (at a specific stream location) is a simplifying assumption used for modeling the effects of the NorthMet Project Proposed Action.

Note that groundwater baseflow does not include other sources of flow to the Partridge River such as surface runoff, temporary bank storage, and Northshore-related discharges including pumped discharges, seepage from the Area 003 West pond, and wetland storage-and-release mechanisms associated with those discharges. Groundwater baseflow as defined for the EIS is ***not*** synonymous with measured low-flows in the river (e.g., 30-day low flows) ***unless*** the effects of Northshore discharges are accounted for when evaluating measured flows. Flow contributions from the Northshore mine-impacted watershed are treated as a separate input for the water modeling impact assessment. Note that in Northshore closure (post-2070) it is expected that there will be no Northshore-related flow contributions to the Upper Partridge River.

The Northshore discharges to the Partridge River are a combination of controlled pumping from the Peter Mitchell Pit, uncontrolled seepage, and occasional surface discharge from the Area 003 West pit lake. The amount of pumping and its temporal distribution varies depending on pit operations and weather conditions. Pumping from the Peter Mitchell Pit to the Partridge River can occur at high flow rates (many 10s of cfs) for durations of several days, followed by longer periods with no pumping. The Northshore discharges are reported to MDNR as monthly volumes rather than flow rates. Monthly volumes resolved into average monthly flow rates are shown on Figure 1. Note that these flows are estimated from pump curves and pump run times and could have inaccuracies. Also, the flows on Figure 1 do not include seepage and surface discharge from the Area 003 West pit lake that likely reaches the Partridge River. Finally, there are also periods when Northshore reported no pumped discharges from the Peter Mitchell Pit to the Partridge River; these were January to February 1985, November to December 1985, and October to December 1986.

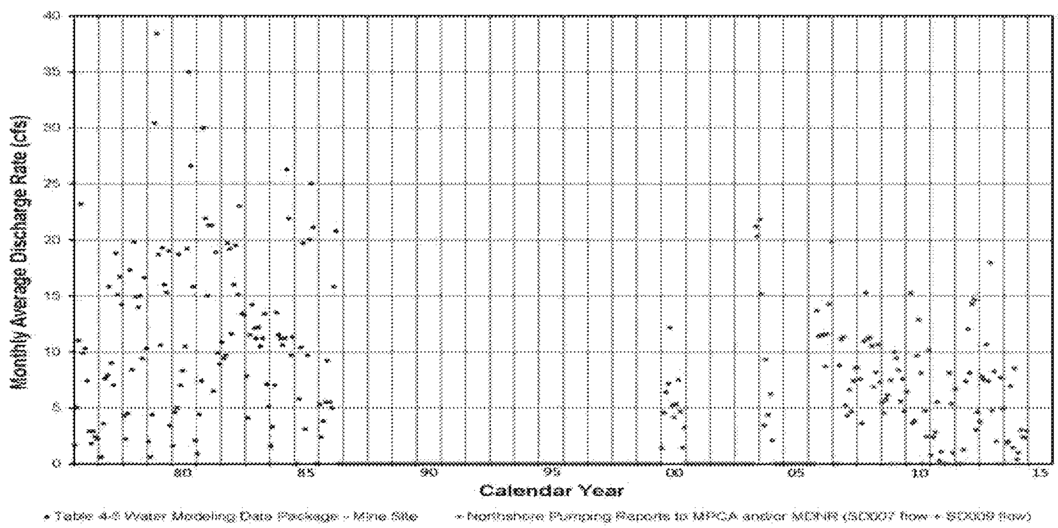


Figure 1 Monthly Average (24/7) Pumped Flow Rate from Peter Mitchell Pit to Partridge River

The groundwater baseflow value for SW-006 in Table 1 is based on water year (WY) stream flows measured at USGS gaging station number 04015475, which is located on the Partridge River just above Colby Lake. A water year goes from October of the preceding year through September of the designated water year. The measured 30-day low-flow at SW-006 for WY 1986 was 8.74 cfs that occurred between Jan-Feb 1986. The low-flow for WY 1987 was 1.21 cfs that occurred between Feb-Mar 1987. These two low-flows average to 4.98 cfs, and this was taken as a preliminary groundwater baseflow rate at SW-006.

For SW-006 and the remaining stations in Table 1, XP-SWMM was used to scale the groundwater baseflows at other upstream Partridge River stations based on their associated contributing watershed areas. The XP-SWMM model was initially calibrated to WY 1985, and validated against the entire 10-year gaged period corresponding to WY 1979-1988, adjusted to account for Peter Mitchell Pit dewatering. Because the XP-SWMM model is intended to assess relative hydrologic impacts (versus "predict" instantaneous flows), model results are multiplied by "scale factors." The scale factors vary according to the flow statistic of interest, and are based on observed data from the period when the Peter Mitchell Pit was not dewatering (October 1986 through September 1988). The goal of the XP-SWMM model was to represent average conditions without the influence of the Peter Mitchell Pit dewatering. As a result the SW-006 preliminary value of 4.98 cfs was adjusted upward slightly to 5.27 cfs; see Mine Site Water Data Package v14; Sections 4.4.1.2.6 and 4.4.1.2.7 (Barr 2015).

Other relevant background includes:

> Groundwater Baseflow Yield. Inflow of water to a groundwater body from the surface is known as recharge or groundwater baseflow yield; this can be calculated for any given watershed. When the SW-006 groundwater baseflow value is normalized to its contributing natural, undisturbed watershed area of approximately 97 mi^2, the groundwater baseflow yield in the Upper Partridge River computes to 0.054 cfs/mi^2. Doing the same analysis for the adjacent Embarrass River watershed using data collected between 1942-1963 (which did not have Northshore or other influences) provided a groundwater baseflow yield of 0.045 cfs/ mi^2. These two values are reasonably similar for neighboring watersheds.
>
> DNR Gaging Station at SW-003. Partridge River flow data are available from a DNR gaging station recently installed at SW-003. A low-flow analysis of this data by MDNR (December 17, 2013) gave a range of 1.3 to 1.8 cfs. When considering whether to use this data in the EIS modeling, the Co-lead Agencies concluded that it is difficult to separate the Northshore discharges from the existing SW-003 flow data in order to estimate groundwater baseflow. Although not incorporated into the EIS modeling, the DNR gaging station data at SW-003 were considered by the Co-lead Agencies in determining the values used in a groundwater baseflow sensitivity analysis.

In light of all these factors the Co-lead Agencies conclude the groundwater baseflow values listed in Table 1 (based on the SW-006 data) account for potential Northshore Mine discharges (i.e., they are regarded to be absent) and are considered a reasonable estimate of recent conditions for FEIS MODFLOW calibration and as inputs to the FEIS GoldSim model effects analysis (MDNR; March 5, 2014).

1.1 Cooperating Agencies Communications RE: Groundwater Baseflow and MODFLOW Calibration

There has been much discussion on the issue of groundwater baseflows to the Partridge River stemming from comments on the SDEIS and communications between the Co-lead Agencies and Cooperating Agencies. The Tribal Cooperating Agencies in particular have provided comments and memoranda stating their opinion that the baseflows used to calibrate the MODFLOW model (and also used as input to the GoldSim model) are erroneously low.

In a letter from GLIFWC dated June 18, 2015, specific concerns were raised about: 1) groundwater baseflows used to calibrate the FEIS models; and 2) bedrock groundwater flow directions between the NorthMet and Northshore mine sites. The flow direction issue is addressed in a separate Co-lead Agencies interagency technical memorandum while the groundwater baseflow calibration issue is addressed in this memorandum.

For groundwater baseflows, the GLIFWC letter raised concerns about the use of 1980s stream gaging data at SW-006 to calibrate the FEIS MODFLOW model, which is intended to represent recent conditions. Due to low pit water levels at Northshore's operations during this time period, GLIFWC contends that groundwater baseflows interpreted from 1980s data are lower than the current groundwater baseflows. GLIFWC concludes: "The result of this mis-match of boundary conditions and calibration targets is that the model is incorrectly calibrated and can not be expected to produce accurate information."

1.2 Analysis

The Co-lead Agencies' review of the summary illustration attached to the GLIFWC letter (Figure 2 herein) suggests that during the 1980s, the Northshore pits intercepted approximately 0.93 cfs of groundwater that otherwise would have become groundwater baseflow to the Partridge River. The Co-lead Agencies further interpret the GLIFWC line of reasoning to suggest that groundwater baseflow at SW-006 could currently be 0.93 cfs higher than the value listed in Table 1, and this would give an Upper Partridge River groundwater baseflow yield of 0.064 cfs/mi2, which is approximately 18% higher than the FEIS value (0.054 cfs/mi2). Applying this higher groundwater baseflow yield (derived from GLIFWC's asumptions) to the other MODFLOW calibration stations would lead to the values summarized in Table 2.

Table 2 Possible Groundwater Baseflows Interpreted by Co-lead Agencies Based on Information Provided in GLIFWC Letter Dated June 18, 2015

Partridge River Station	FEIS Groundwater Baseflow (cfs) (Table 1)	Possible Current Groundwater Baseflow Based on GLIFWC Letter (cfs)
SW-002	0.41	0.48 [c]
SW-003	0.51	0.60 [c]
SW-004	0.92	1.09 [c]
SW-006 [b]	5.27	6.20 [a]

[a] Add 0.93 cfs to SW-006 groundwater baseflow estimated from 1980s gaging data (5.27 cfs), which increases SW-006 groundwater baseflow by 18%.
[b] Same as historical USGS gaging station #04015475.
[c] Assuming more or less uniform recharge (groundwater baseflow yield) throughout the natural watershed, increase groundwater baseflow at other stations by 18%.

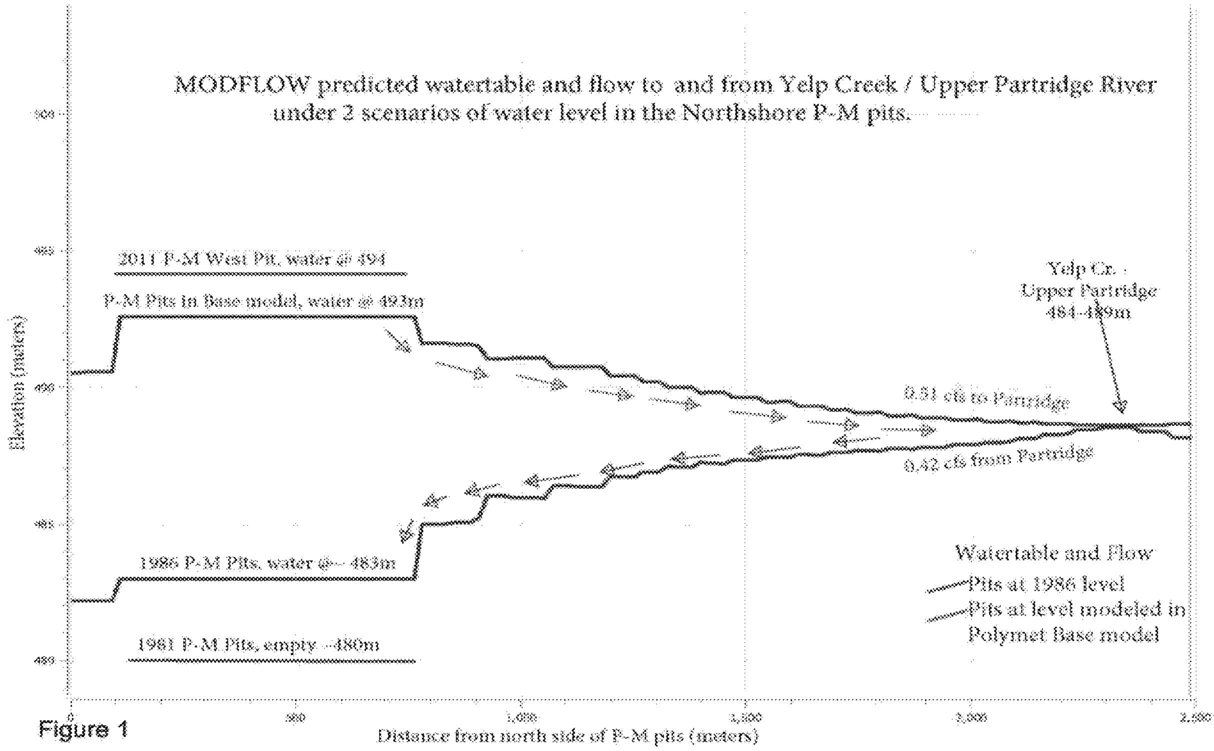


Figure 1

Figure 2 GLIFWC Summary Illustration from June 18, 2015 Correspondence

Whereas the Co-lead Agencies continue to consider the Table 1 groundwater baseflows as reasonable values that should be retained for FEIS modeling, the *possibility* that the Table 2 values could exist for current conditions is acknowledged. In this context the Co-lead Agencies note the GLIFWC letter further states:

"*There appear to be two options to resolve these fundamental errors*:

Calibrate the MODFLOW model to 1986-88 conditions, with the P-M pits set at their correct late 1986 to early 1988 levels, and use the 0.51 cfs baseflow rate at SW003 (and other 1986-88 baseflows at other stations) as targets. This would result in a very different hydrologic model for the site so as to account for the loss of groundwater to the P-M pits. This appears to be a poor option because of the significant uncertainty about the baseflow in the Partridge River in 1986-88 and uncertainty about the exact level of water in the P-M pits. [Referred to herein as **GLIFWC Option #1**]

Or

Calibrate the MODFLOW model to 2011 conditions, with the multiple P-M pits at their known 2011 water levels of 483 to 499m (pit water elevations are available for that year), and use estimates of baseflow at SW003 based on current data. There is more certain information for both the water levels in the taconite pits and the baseflow in the Partridge River. The December 2013 DNR analysis of 2011-12 flows at

SW003 indicate that "minimum winter base flows" in the range of 1.3 to 1.8 cfs are reasonable." [Referred to herein as **GLIFWC Option #2**]

The Co-lead Agencies do not consider GLIFWC Option #1 to be a viable option because other calibration data, such as measured groundwater levels in surficial deposits and bedrock, would be limited or nonexistent for the mid-1980s time period. The Co-lead Agencies do consider GLIFWC Option #2 to be a workable approach for investigating the effect of higher groundwater baseflows on predicted water quality and quantity effects associated with the NorthMet Project Proposed Action. If pursued, GLIFWC Option #2 would increase the groundwater baseflows at all locations used to calibrate the MODFLOW model by a factor of 2.5 to 3.5 times higher than the groundwater baseflows used to calibrate the FEIS model (listed in Table 1). This is also much higher than the approximately 18% increase interpreted from the illustration attached to the GLIFWC letter (See Figure 2).

2.0 Co-lead Agencies Directed Groundwater Baseflow Sensitivity Analysis

Because of issues raised by the Cooperating Agencies on the groundwater baseflow estimates being used in the EIS-related water resources impact assessments, the Co-lead Agencies directed PolyMet to conduct a comprehensive sensitivity analysis (using both the MODFLOW and GoldSim models) to assess if higher groundwater baseflows would cause the NorthMet Project Proposed Action to exceed applicable water quality evaluation criteria. The idea was to evaluate NorthMet Project Proposed Action effects using significantly elevated groundwater baseflows to test model sensitivity for this parameter. If the analysis showed that unacceptable NorthMet Project Proposed Action effects were predicted for the higher groundwater baseflows in the Partridge River, then there would be justification to further investigate and characterize groundwater baseflows within the Partridge River watershed and potentially modify the predictive models accordingly. On the other hand if the analysis showed that NorthMet Project Proposed Action effects remained acceptable (e.g., that is, would continue to meet the applicable water quality evaluation criteria), then it would be concluded that while groundwater baseflows have some uncertainty, the range of uncertainty does not affect the NorthMet Project Proposed Action's predicted ability to meet the applicable evaluation criteria.

Although the groundwater baseflow sensitivity analysis was performed in January 2015 prior to receipt of the GLIFWC June and August 2015 letters, the Co-lead Agencies consider the sensitivity analysis as being consistent with GLIFWC Option #2. For the groundwater baseflow sensitivity analysis, all groundwater baseflows along the Partridge River were increased by a factor of 4 as shown in Table 3. The factor of 4 increase is greater than the range proposed in the GLIFWC Option #2 recommendation (2.5 to 3.5 times higher) and is much greater than the approximately 18% increase suggested by the Co-lead Agencies' interpretation of the GLIFWC illustration.

In response to the Co-lead Agencies conclusion that the groundwater baseflows sensitivity analysis being consistent with GLIFWC Option #2, that agency commented in its August 11, 2015 letter that "[i]t has been proposed that sensitivity analysis can substitute for understanding site hydrology. While sensitivity analysis on a properly bounded and calibrated model provides insights on the range of possible predictions, sensitivity analysis conducted on a grossly mis-configured model can not be depended on." The Co-lead Agencies note the sensitivity analysis is not a substitute for correct MODFLOW bounding and calibration, but was conducted in response to broader concerns identified by GLIFWC regarding the appropriateness of the groundwater baseflows used in the EIS. Of important note the sensitivity analysis was independent of MODFLOW. The Upper Partridge River baseflows were an independently derived input into MODFLOW, not an output from the model. Therefore the sensitivity analysis was really unaffected by MODFLOW assumptions.

Table 3 Groundwater Baseflows Used for Sensitivity Analysis (Barr, January 2015)

Partridge River Station	Groundwater Baseflows used for Sensitivity Analysis (cfs)
SW-002	1.62
SW-003	2.04
SW-004	3.66
SW-006	21.1

Details of the groundwater baseflow sensitivity analysis are provided in the report Sensitivity Analysis of the NorthMet Water Quality Models – Version 2, NorthMet Project (Barr; January 2015). A summary of the sensitivity analysis method is provided below:

- For MODFLOW calibration, use groundwater baseflows listed in Table 3.
- Perform a complete recalibration of the current-conditions MODFLOW model using higher groundwater baseflows (Table 3) and groundwater levels measured in monitoring wells completed in both surficial deposits and bedrock.
- Transfer results of recalibrated MODFLOW Model to the Mine Site GoldSim model. These mainly include higher pit inflows, higher hydraulic conductivities of surficial deposits, and higher aquifer recharge rates.
- Consistent with previous Co-lead Agencies recommendations for the GoldSim model, increase average discharge from Northshore into the Partridge River from 1.0 to 2.6 cfs and increase the sulfate concentration of this discharge from 22 to 28 mg/L.
- Using the current-conditions GoldSim model, perform a complete recalibration of surface runoff chemical concentrations.
- With the new (sensitivity) inputs, run the GoldSim model to perform a complete NorthMet Project Proposed Action effects analysis.
- Evaluate the effects of higher groundwater baseflows on GoldSim-predicted surface and groundwater concentrations, and determine if these concentrations lead to modeled exceedances of applicable water quality evaluation criteria.

The Co-lead Agencies acknowledge that the sensitivity recalibration of the Mine Site MODFLOW model used the previous water-level elevation for the Northshore pits (493 m msl) rather than the range of 483 to 499 m msl recommended by GLIFWC. The stated purpose of the MODFLOW model is to predict pit inflows and characterize hydrogeologic conditions between the NorthMet mine pits and the Partridge River. Given this purpose, the Co-lead Agencies consider that using 493 m msl for Northshore pit water levels to be an adequate approximation to be used in the model for the groundwater baseflow sensitivity analysis. For additional information on different Northshore Mine pit lake elevations, see: "Co-lead Agencies' Consideration of Possible Mine Site Bedrock Northward Flowpath;" Interagency Technical Memorandum; October 12, 2015.

Detailed results of the groundwater baseflow sensitivity analysis are presented in the report "Sensitivity Analysis of the NorthMet Water Quality Models –Version 2 (Barr; January 2015). A general summary of the results is provided below:

- Year 20 West Pit groundwater inflows transferred from MODFLOW to GoldSim increased from 80 to 140 gpm.
- Year 11 East Pit groundwater inflows transferred from MODFLOW to GoldSim increased from 760 to 860 gpm.
- Median (P50) aquifer recharge transferred from MODFLOW to Goldsim increased from 0.75 to 2.9 in/yr.
- Median (P50) hydraulic conductivities for the 5 surficial groundwater flowpaths in GoldSim increased as follows:
    - West Pit flowpath: from 1.31 to 5.15 m/day;
    - Overburden Storage Laydown Area (OSLA) flowpath: from 3.55 to 5.26 m/day;
    - Waste Water Treatment Facility (WWTF) flowpath: from 0.88 to 2.53 m/day;
    - Ore Surge Pile (OSP) flowpath: from 0.52 to 2.01 m/day; and
    - East Pit - Cat 2/3 Stockpile flowpath: from 1.94 to 7.59 m/day.

Regarding groundwater quality, the effect of increased groundwater baseflows on GoldSim-predicted impacts is summarized as follows:

- There was more rapid transport (reduced travel time) of solutes from Mine Site sources to the groundwater evaluation locations and to the Partridge River.
- Peak groundwater concentrations at the groundwater evaluation locations tended to be higher.
- In no case was there a new exceedance of a groundwater evaluation criteria at the 90th percentile (P90) concentration.

Regarding surface water quality in the Partridge River, there were noticeable increases in the concentrations of some constituents for the high groundwater baseflow model. However, no constituents exceeded their surface water quality evaluation criteria except for aluminum and sulfate, which occurred in both the FEIS and high groundwater baseflow models due to elevated background concentrations rather than the influence of the NorthMet Project Proposed Action. For these:

> Aluminum. For the high groundwater baseflow model, the predicted frequency of aluminum exceedance for the NorthMet Project Proposed Action (when Continuation of Existing Conditions [CEC] does not) was nearly identical to results of the FEIS model and did not exceed 1.6% when evaluated using annual maximum concentrations.
>
> Sulfate. For the high groundwater baseflow model, the predicted frequency of sulfate exceedance at SW-005 (where the 10 mg/L wild rice standard applies) is similar to the FEIS model. A comparison of the high groundwater baseflow model and results of the FEIS model is provided in Table 4. For the time period of 0 to 55 mine years, the frequency of exceedance for the NorthMet Project Proposed Action (when CEC does not exceed) is zero or very small for both the FEIS model and high groundwater baseflow model. For the time period of 55 to 200 years, the frequency of exceedance is zero for both models when P50 concentrations are considered. For P90 concentrations, the frequency of exceedance is zero for the FEIS model and 3.6% for the high groundwater baseflow model. The 3.6% frequency of exceedance in the high groundwater baseflow model is below the screening criterion of 10% used in previous PolyMet evaluations and the more conservative 5% used in the FEIS. Note that for the high groundwater baseflow model, the maximum difference in sulfate concentrations between NorthMet Project Proposed Action and CEC conditions for all time steps is only 0.27 mg/L.

Table 4 GoldSim-Predicted Sulfate Concentrations at SW-005 for FEIS Model (Version 6) and High Groundwater Baseflow Model [a]

Time Period (myr)	Description	Units	Based on P50 Values		Based on P90 Values	
			FEIS V6	High Baseflow	FEIS V6	High Baseflow
0-55[1]	Percentage of time that PA concentration > 10 mg/L	%	29.0	33.4	100.0	100.0
	Percentage of time that CEC concentration > 10 mg/L	%	28.9	33.4	100.0	100.0
	Percent of time that PA concentration > 10 mg/L ***and*** CEC concentration <= 10 mg/L	%	0.3	0.0	0.0	0.0
	Maximum (PA concentration - CEC concentration)	mg/L	0.055	0.101	0.087	0.153
55-200[2]	Percentage of time that PA concentration > 10 mg/L	%	0.2	0.2	100.0	93.4
	Percentage of time that CEC concentration > 10 mg/L	%	0.2	0.2	100.0	91.4
	Percent of time that PA concentration > 10 mg/L ***and*** CEC concentration <= 10 mg/L	%	0.0	0.0	0.0	3.6
	Maximum (PA concentration - CEC concentration)	mg/L	0.273	0.268	0.102	0.265

PA NorthMet Project Proposed Action concentration
CEC Continuation of Existing Conditions concentration
CRT Applicable evaluaton criterion (10 mg/L)
[1] Northshore discharges 2.6 cfs with sulfate concentration of 28 mg/L; no WWTF discharge
[2] WWTF discharges at average rate of 0.67 cfs with sulfate concentration of 9 mg/L; no Northshore discharge
[a] FEIS V6 values are the same as those reported in PFEIS Table 5.2.2-34

For Colby Lake, exceedances are predicted in the FEIS model for arsenic, copper, iron, and manganese. These exceedances are also predicted in the high groundwater baseflow model, but the frequency of exceedance for the NorthMet Project Proposed Action (when CEC does not) did not exceed 4% for any constituent evaluated using annual maximum concentrations.

Based on the groundwater baseflow sensitivity analysis, the Co-lead Agencies conclude the following:

- Groundwater and surface water constituent concentrations show observable sensitivity to groundwater baseflow values, with higher concentrations generally associated with higher groundwater baseflows.
- Despite the effect on concentrations, the NorthMet Project Proposed Action does not exceed applicable water quality evaluation criteria, even for the unlikely case of groundwater baseflows being 4 times higher than the values used in the FEIS.

3.0 Discussion

The Co-lead Agencies have previously concluded that groundwater baseflow values used to calibrate the current-conditions Mine Site MODFLOW model, and as inputs to the GoldSim water quality model, are reasonable estimates of current hydrologic conditions for the Partridge River at the NorthMet Mine Site. However, because there are differences between the Co-lead Agencies and the Cooperating Agencies on the issue of groundwater baseflow, a sensitivity analysis was performed using groundwater baseflows that were 4 times higher than the values used in the FEIS, and also higher than the range of values recommended by GLIFWC in its letter dated June 18, 2015. The Co-lead Agencies believe that the groundwater baseflow sensitivity analysis adequately responds to the Option #2 recommendation made by GLIFWC in terms of understanding potential impacts to water quantity and quality. The sensitivity analysis is also not considered a substitute for correct MODFLOW bounding and calibration, but allows for consideration of broader concerns raised by GLIFWC regarding groundwater baseflows used in the EIS.

The results of the groundwater baseflow sensitivity analysis indicate that estimated constituent concentrations show some sensitivity to the increase in groundwater baseflow values at the respective evaluation locations. Specifically:

> Groundwater. For the high groundwater baseflow model there were observable differences between it and the FEIS Version 6 model results, but did not result in any new exceedances of the applicable groundwater quality evaluation criteria for the NorthMet Project Proposed Action. There was however more rapid transport (reduced travel time) of solutes from Mine Site sources to the groundwater evaluation locations and to the Partridge River under the high groundwater baseflow model.
>
> Surface Water. There were noticeable increases in the concentrations of some constituents in the Partridge River and Colby Lake for the high groundwater baseflow model. However, where surface water quality evaluation criteria were exceeded, the frequency of exceedance of the NorthMet Proposed Action Project (when CEC does not exceed) was either very similar to the FEIS model results or did not exceed the 5% screening criterion used in the FEIS.

The above observations apply even for the unlikely case of groundwater baseflows being 4 times higher than the values used in the FEIS, which is higher than GLIFWC's Option #2. Consequently the Co-lead Agencies conclude there is no methodology-based justification for changing the groundwater baseflow values used in calibrating the EIS Mine Site MODFLOW and GoldSim models for water resources impact evaluation.

4.0 References

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APPLIED GROUNDWATER MODELING

Simulation of Flow and Advective Transport

Second Edition

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omitting natural world detail important to the forecast (Box 10.2). In these cases, more sophisticated approaches that better represent important system detail are warranted.

10.4 BASIC UNCERTAINTY ANALYSIS

A basic uncertainty analysis focuses on a small set of dominant factors expected to drive forecast uncertainty and uses approximate but computationally efficient representations of uncertainty (Fig. 10.6). Using the two sources of uncertainty described in Section 10.2, *scenario modeling* addresses uncertainty in future conditions and *linear uncertainty analysis* addresses uncertainty stemming from the base model.

10.4.1 Scenario Modeling

In scenario modeling, all initial parameters and hydrologic conditions from the base model are retained except for those explored as part of the forecast. The base model, modified for a set of future conditions, represents a *scenario* or *projection* of the future. The scenario is executed as a forward run, a relatively small number of times (typically

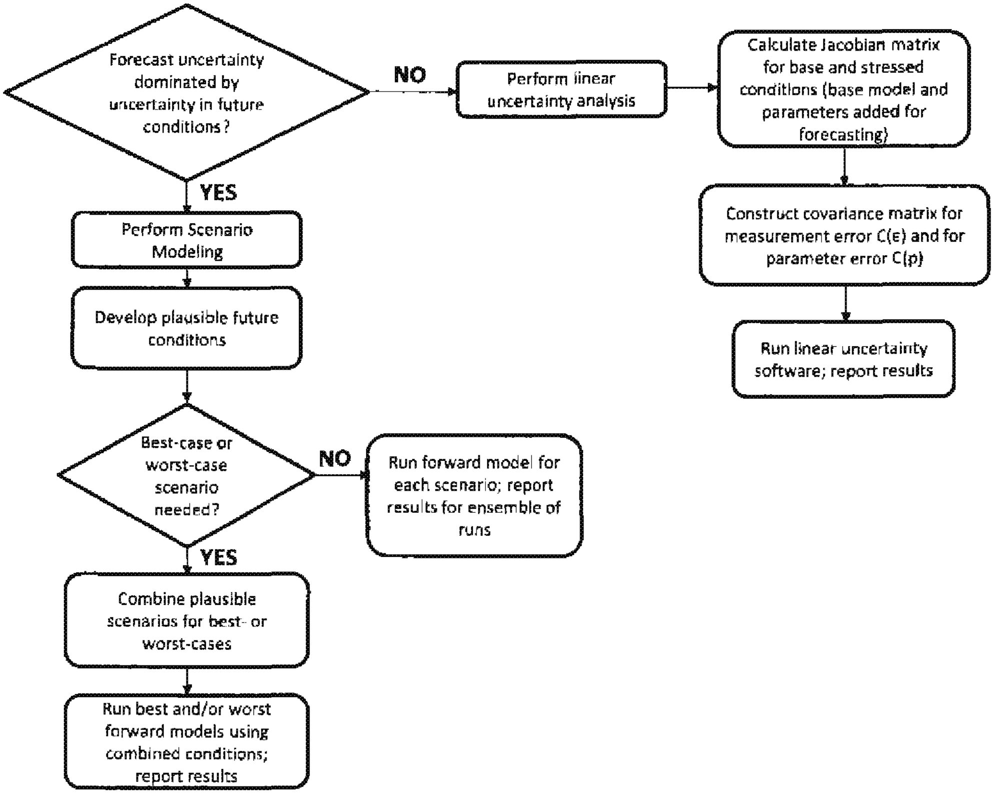

Figure 10.6 Schematic diagram of a potential workflow for performing basic uncertainty analysis.

fewer than 20). Each run is executed with different assumed values (determined by the modeler) for future conditions. One objective of scenario modeling is to produce an ensemble of results that defines a representative envelope of uncertainty around the forecast. For example, several different pumping rates and/or variations in recharge rates during wet and drought periods might each constitute a scenario.

A scenario might assume that system dynamics are constant over time (e.g., the system and drivers have the same mean and variance over time, called *stationarity*); alternatively, a scenario can encompass conditions with dynamics that differ from the base model. Simulations using different future climates are examples of scenarios that are nonstationary. Future scenarios can also be formulated to simulate future maximum and minimum responses, and might include combinations of future stresses. The intent of such an analysis is to bracket the forecasts of the base model with a range of forecasts that represent a reasonable envelope of *best-* or *worst-case* scenarios. Often construction of such a scenario is straightforward ("what is the effect of extreme drought on groundwater discharge?"). In other cases, the response of a complex model to altering multiple parameters and stresses may not be obvious, and other more advanced methods such as a maximization—minimization uncertainty analysis (Section 10.5) may be required.

An example of scenario modeling is shown in Fig. 10.7, where the purpose of the model was to assess effects of possible future climates on stream baseflow. To represent the uncertainty inherent to future climate predictions, 15 forecasts were made using precipitation and temperature output from three potential CO_2 emission scenarios (derived

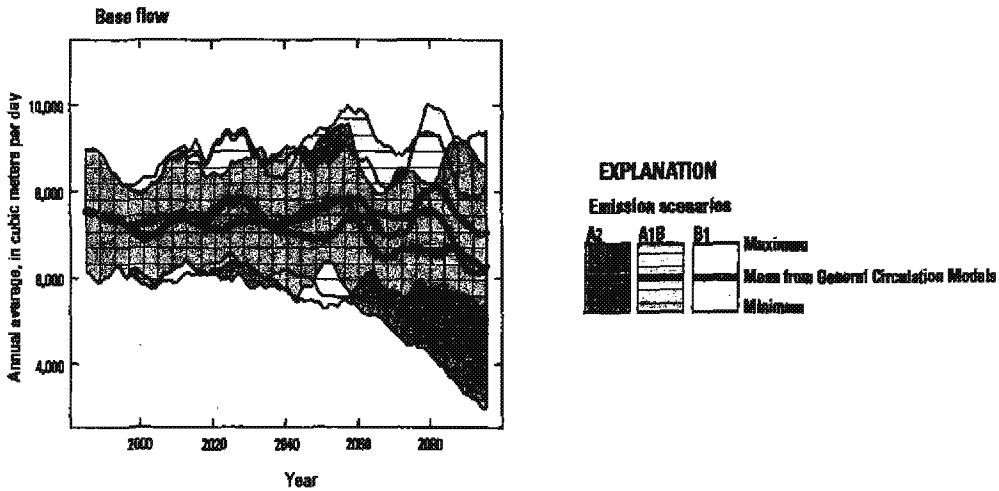

Figure 10.7 A forecast of baseflow summarizing 15 scenario forward runs (maximum, minimum, and average conditions in each of three emission scenarios). Forecast uncertainty is shown by the envelope around the means of the three scenarios (colored lines). The forecasts derived from the mean of each emission scenario were based on the mean results from 5 different General Circulation Models. Note how the uncertainty envelope increases with time *(Hunt et al., 2013).*

using five different General Circulation Models or GCMs). The range in the 15 forecasts is illustrated by the outer envelope of results in Fig. 10.7; the mean result for a given emission scenario is shown by a colored line. Important points regarding uncertainty are illustrated by the results: (1) there can be no expectation of one "best" forecast given the uncertainty about future climates; (2) uncertainty in the forecasts increases with time; (3) there is appreciable difference in climate among the five GCMs even for the same emission scenario; (4) effects of CO_2 emissions on baseflow are forecast to be most pronounced during the later portion of the twenty-first century. Note that since there is so much variability in the future climate driver, no attempt was made to include the additional uncertainty contributed to the forecasts from the base model; it is negligible for this forecast compared to the uncertainty in the climate driver.

10.4.2 Linear Uncertainty Analysis

Linear uncertainty analyses require few alterations to the base model. They are typically computationally frugal because only sensitivities are required, and are appropriate for both overdetermined and underdetermined inverse problems. The Jacobian matrix described in Section 9.5 is the basis of linear uncertainty analysis. Recall that the Jacobian matrix is composed of parameter sensitivities, which relate changes in model parameters to changes in model outputs. Linear methods are computationally easy to implement because the Jacobian matrix is calculated only once. However, they do require the calculation of additional sensitivities for each forecast and the modeler's assessment of uncertainty in parameters and observations (the "prior"). In the simplest case, measurement error propagates uncertainty to calibration parameters (e.g., Fig. 10.8), which in turn can be related to uncertainty in model forecasts (e.g., see Hill and Tiedeman, 2007, p. 159). However, as shown in Fig. 10.2, measurement error is only one component of model uncertainty; parameter simplification error can be an important contributor to forecast uncertainty, especially if the model is sparsely parameterized.

In recognition of its importance, a method for estimating parameter simplification error was developed by Cooley (2004) where multiple realizations of a complex hydraulic conductivity field were translated to simpler zones. However, this analysis was computationally demanding, and at the end the modeler had to decide if the simplification error was acceptable. If not, the model parameterization, calibration process, and evaluation of parameter simplification error had to begin again. Moore and Doherty (2005) discuss a more computationally efficient approach for including both measurement error uncertainty and simplification uncertainty in a linear uncertainty analysis. Given there is readily available software for applied modeling, we use the Moore and Doherty (2005) formulation here as an example of including both simplification and measurement error in forecast uncertainty estimates.